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GASBUGGY

PRELIMINARY POSTSHOT SUMMARY REPORT

FRED HOLZER

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Livermore

A GOVERNMENT-INDUSTRY EXPERIMENT

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U.S. ATOMIC ENERGY COMMISSION
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U.S. DEPARTMENT OF INTERIOR

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CIVIL, INDUSTRIAL AND SCIENTIFIC USES FOR NUCLEAR EXPLOSIVES

Project Gasbuggy is a joint effort under the U. S. Atomic Energy Commission's Plowshare Program by El Paso Natural Gas Company, the Bureau of Mines of the U. S. Department of Interior and the Atomic Energy Commission with technical assistance provided by Lawrence Radiation Laboratory, Livermore, California. This report was prepared as a part of project performance.

This report has also been issued as UCRL-50386.

~~Printed in USA. Price $3.00.~~ Available from the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U. S. Department of Commerce, Springfield, Virginia 22151.

PNE-1003
(TID-4500, UC-35)
Nuclear Explosions—
Peaceful Applications

GASBUGGY PRELIMINARY POSTSHOT SUMMARY REPORT

Fred Holzer

Lawrence Radiation Laboratory
Livermore, California

January 1968

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U. S. ATOMIC ENERGY COMMISSION
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PREFACE

This report summarizes some of the early, preliminary results from Project Gasbuggy in order to answer the many questions about this unique experiment. No definitive results are available which speak to the primary purpose of the experiment, namely the changes in the deliverability and ultimate recovery of the reservoir gas; these must await the detailed exploration and gas production tests. While every attempt has been made to present accurate data, it must be recognized that they are preliminary and subject to change. Thus the analysis of a complete set of data may point to inconsistencies in individual points which were unsuspected in an earlier analysis. Conclusions based on incomplete data may also turn out to be incorrect, and require correction or modification. The limitations inherent in the results presented here should therefore be clearly kept in mind.

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GASBUGGY PRELIMINARY POSTSHOT SUMMARY REPORT

ABSTRACT

The Project Gasbuggy nuclear explosion of nominally 26-kt yield was detonated on Sunday, December 10, 1967, at 12:30:00 Mountain Standard Time. Indications are that the explosive performed satisfactorily. Preliminary information is available on subsurface and surface ground motions, on the extent of the fractures, on the gas pressure in the chimney, and on the concentration of radionuclides. Subsurface ground velocities measured in instrument hole GB-D located 1470 ft from the emplacement hole range from about 1.15 to 1.6 m/sec depending on the gage location. These values are somewhat but not surprisingly higher than expected. Peak surface velocities range from 1.6 m/sec at the surface above the explosion to about 0.4 m/sec 8400 ft away. Both these data as well as preliminary values of ground motion out to a range of 60 miles are in very good agreement with preshot expectations. No damage was sustained by any of the conventional gas wells which were as close as 2600 ft to the explosion, and no structural damage has been reported from the surrounding area. Reentry drilling through the 7-in. casing on which the explosive canister was lowered established connection with the chimney at a depth of 3907 ft below the ground surface. A gas pressure of 833 psi was measured at the surface, and some xenon-133 activity was detected in samples. No other radioactive nuclide has been detected in the gas, although gas samples taken at depth have not as yet been analyzed. Density, gamma-radiation, and caliper logs indicate that a number of breaks or offsets have occurred ranging from 3805 ft down to the void at 3907 ft. These locations are in good agreement with data from fracture instrumentation in GB-1, correlate with preshot rock weaknesses, and compare favorably with predictions. Data from preliminary short term flow tests are not conclusive, and cannot be considered significant relative to either reservoir evaluation or chimney volume determination. Future work should shed light on the connection of the reentry hole with the chimney and on the nature of the chimney itself.

INTRODUCTION

The Project Gasbuggy nuclear explosive of nominally 26-kt yield was detonated on Sunday, December 10, 1967, at 12:30:00 Mountain Standard Time at a depth of 4240 ft below the ground surface, about 55 air miles east of the city of Farmington, New Mexico. The location of the explosion was 1770 ft from the west line and 1218 ft from the south line of Section 36, Township 29 North, Range 4 West in Rio Arriba County, New Mexico, corresponding to geodetic coordinates of latitude 36° 40'40" North, longitude 107° 12'30" West, at an elevation of 2964 ft above mean sea level. The detonation occurred in the Lewis Shale formation of the San Juan Basin about 40 ft below its contact with the gas-bearing Pictured Cliffs sandstone. Indications are that the explosive performed satisfactorily.

The purpose of the Gasbuggy experiment is to determine to what extent a low-permeability natural gas formation can be stimulated by an underground nuclear detonation and to identify the detonation-associated effects which cause the stimulation. Specifically, the experiment was designed to achieve these objectives:

1. To measure the changes in the deliverability and ultimate recovery of the gas, and insofar as possible to identify the changes responsible.

2. To measure any radioactivity of the gas, to study the thermodynamics and chemical reactions of the mixture of gaseous fission products and methane, and to evaluate any necessary control measures.

3. To measure and to evaluate the generation and propagation of seismic energy within the San Juan Basin as part of a continuing study of ground motion and its effect on structures.

The preshot program and the preparation for the shot-time measurements were described in the Preshot Summary Report.[1] Since the detonation of the explosive, data analysis and reentry drilling have progressed to the point where preliminary information from measurements taken at shot time is available on the subsurface and surface ground motion, and on the extent and gas pressure of the chimney caused by collapse of the cavity. Some preliminary data on the concentration of radioactivities in the gas are also available. The present report summarizes these data.

SURFACE REENTRY AND EFFECTS

About 1 hr after the detonation, a limited number of people were dispatched to the recording trailer park and to surface ground zero to recover data and to monitor the area for radioactive contamination. No obstacle was encountered to

normal automobile travel from the control point, and no radioactivity above background level was detected anywhere on the surface. The two radiation meters at depths of 300 and 3000 ft in the emplacement hole also showed only background readings.

On the leveled area on the ground above the explosion, very little evidence of any surface disturbance was visible. Figures 1 and 2 show the GB-E and GB-1 well-head installations as they appeared immediately after reentry. A few minor cracks in the dirt access road were soon obliterated by traffic. A cable reel left some 300 ft from the GB-E well head suffered a bent axle, and there was some minor damage to electronic equipment at the recording trailer park and at the control point.

One of the early reentry parties inspected the surface facilities of the gas wells within 5 miles of the site. At the six closest wells at ranges between 2670 and 6750 ft from surface ground zero, some of the separator-dehydrators had moved between 1 to 3 in. from their original positions, and at the four wells within 1 mile, some cracking of the ground around the well head was observed. In no case was the function of the well impaired. The surface pressure recorders at these well heads continued to operate, and no abrupt changes in the pressure buildup of these wells were observed. No radioactivity or other problems were encountered in retrieving downhole pressure gages which were installed in three of the wells before the detonation.

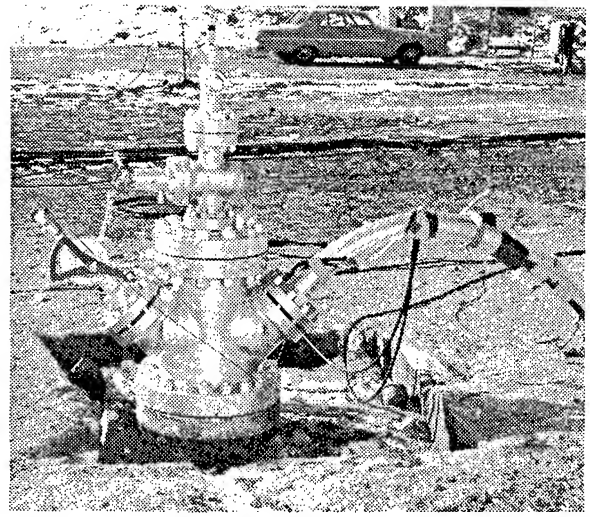

Fig. 2. GB-1 well-head installation immediately after reentry; photograph taken at the same time as that of Fig. 1. Note that some rather flimsy wires are still in place.

Fig. 1. GB-E well-head installation immediately after reentry, about 3 hr after shot time. The area is being checked for the presence of gaseous radioactivity; none was found.

At about 8 hr after the detonation, a small amount of radioactivity was detected at the ground surface in the multiconductor arming and firing cable. This gaseous

activity, consisting of xenon and krypton, had evidently been forced into the interstitial spaces between the conductors and subsequently migrated up the cable. About 1-1/2 hr later all cables coming from GB-E were cut at the well head and sealed off with a cap. It is estimated that during the time of cable cutting, about one curie of gaseous activity escaped to the atmosphere. A maximum dose rate of about 600 mR/hr was read at the cap shortly after the cables were cut. This reading had decreased to 48 mR/hr 8 hr later, at which time all but a small area immediately adjacent to the well head was opened to normal activity.

GROUND MOTION MEASUREMENTS AND RESULTS

GEOPHONE DATA

In order to ascertain the approximate time after the detonation at which the cavity collapsed and the chimney formed, as well as to establish a safe time for area reentry, three geophones were placed just below the ground surface at distances of 2600, 4200, and 8400 ft from surface ground zero. Only the geophone at 8400 ft continued to operate through the immediate postshot interval. Its records show very large initial excursions (due to direct ground shock), gradually decreasing to background at about 1 min after the explosion. With the exception of a few short, relatively low-amplitude signals at around 10 min, no further excursions were detected in the next 18 hr. The conclusion is that the cavity collapsed very soon after its formation, most likely within the first 30 sec.

CLOSE-IN SUBSURFACE SHOCK AND FRACTURE

A number of instruments to measure peak shock pressure, shock velocity, cavity collapse, and fracture propagation were installed in emplacement hole GB-E and in instrument hole GB-1, about 190 ft away. Unfortunately, a subsurface pump overheated during the stemming of the emplacement hole, which caused all instrument cables in this hole to short out and resulted in complete loss of peak pressure and chimney formation information.

Hole GB-1 was instrumented about two months prior to the detonation; Fig. 3 shows one of the instruments in the process of being lowered. On the day before the shot, the resonance cable of the slifer instrument[2] shorted at the oscillator (presumably from corrosion or leakage). Nevertheless, a few time-of-arrival points were obtained and are compared in Fig. 4 with curves calculated on the SOC code.[3]

Of considerable interest are the data from the fracture cable system installed in GB-1. In this measurement, discontinuities in a 1/4-in. diam, stiff electrical cable are recorded as they progress up from the shot horizon. Figure 4 shows that the cable is severed at discrete points up to the 3800-ft level, at a time

closely corresponding to the passage of the stress wave. This measurement indicates a fracture radius of about 440 ft; preshot predictions ranged from 334 to 393 ft,[1] or within 10 to 20% of the measured value.

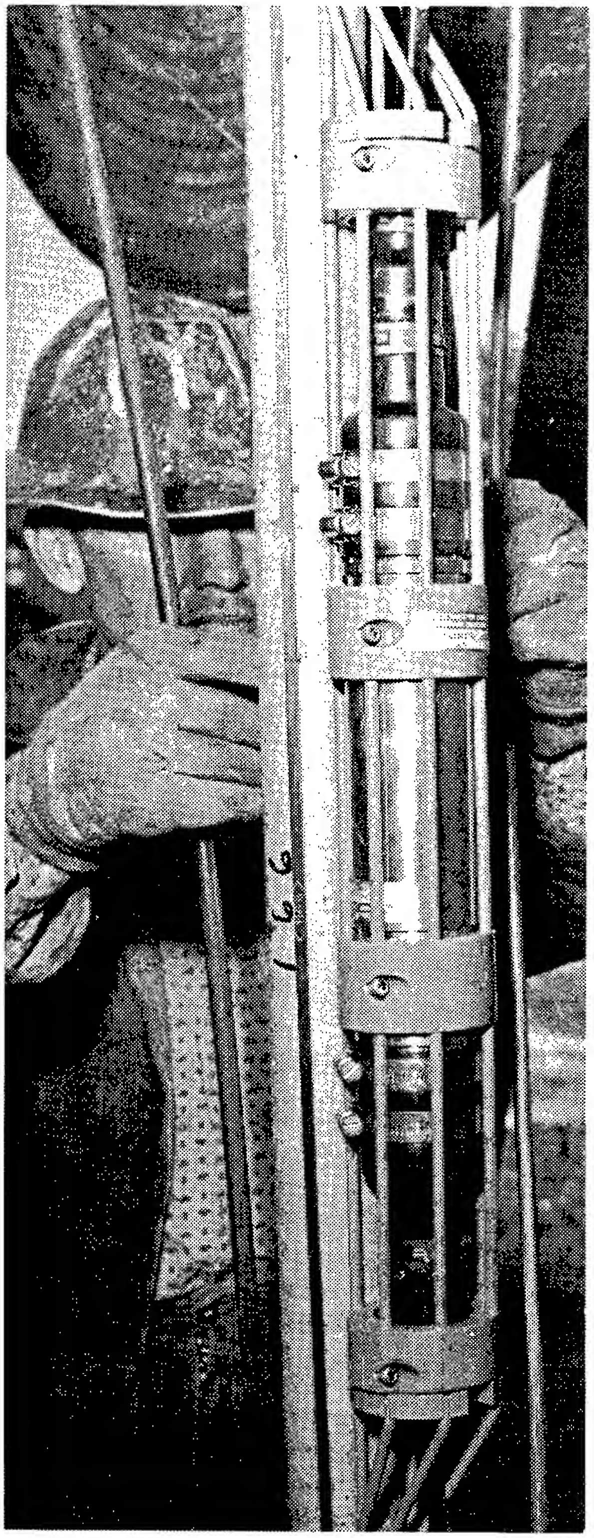

Fig. 3. Instrument being lowered in hole GB-1. Grout was pumped through the fiberglass pipe to which the instrument is attached to provide coupling with the formation.

SUBSURFACE ACCELERATIONS AND VELOCITIES

Acceleration and velocity gages were emplaced at four depths in instrument hole GB-D, located 1470 ft from the emplacement hole. These measurements, carried out by Sandia Laboratories, were made primarily to study the generation of the seismic wave.[4] The detailed results are presented by W. Perret.[5] These data also permit a correlation of ground motion with the ability of conventional gas wells to withstand such motions. Results of a preliminary data reduction are given in Table I, where the station designations correspond to gage depths below the surface in hundreds of feet. All acceleration gages were saturated; this was partly due to accelerations higher than expected, and partly due to the influence of the downhole temperature on instrument damping. The velocities are also somewhat higher than expected, with displacements about as predicted. These facts are consistent with a stress wave of relatively sharp rise time and short duration.

SURFACE ACCELERATIONS AND VELOCITIES

Surface accelerations and velocities were measured over distances spanning

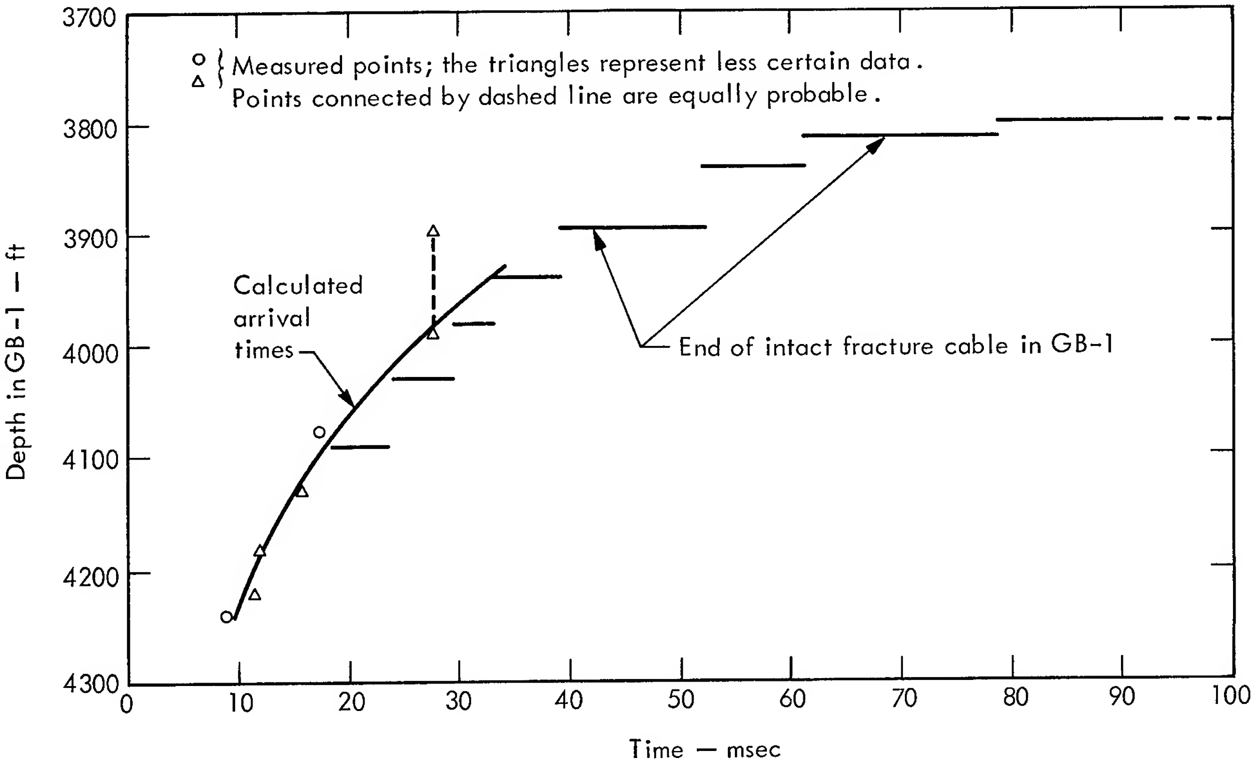

Fig. 4. Dynamic shock and fracture data. The fracture data show that the cable breaks progressively from the bottom; it remains intact above the 3800-ft level.

Table I. Subsurface ground motions from GB-D.[a]

	Peak acceleration (g)			Peak velocity (cm/sec)				Resultant peak displacement[b]
Station	Vertical	Radial	Tangential	Vertical	Radial	Tangential	Resultant	(cm)
U-32	4.6[c]	7.0[c]	1.0	92	98	15	134	3.7
U-36	4.5[c]	11.0[c]	2.9	82	140	15	159	4.1
U-41	3.0[c]	13.0[c]	3.1	61	—	24	—	—
U-46	5.0[c]	16.0[c]	5.5	70	98	21	113	3.6

[a]Data furnished by Sandia Laboratories.

[b]Derived from measured velocities.

[c]Gages saturated at these values.

the range from 100 ft from SGZ out to about 300 miles. These measurements were made by a variety of agencies using a variety of instruments; the results that are reported here cover the range to about 70 miles which is the area of direct interest

to the objectives of Gasbuggy. The preliminary data are compared with preshot predictions in Figs. 5 and 6. A considerable amount of data, primarily velocity information in the 20- to 70-mile range, remains to be reduced and analyzed; the agreement of data with predictions is seen to be quite good.

Out to a distance of at least two depths of burial, surface spall (the separation of a surface layer from the ground) appears to have taken place. This is shown by the values of peak surface motion listed in Table II. Two distinct periods of maximum motion are observed, the first occurring when the stress wave is first incident at the surface, and the second when the separated layer returns to contact the unspalled surface. As observed in other underground explosions, this second peak (due to closing of the surface spall) is up to three times higher than the first.

Part of the seismic array consisted of five stations on or near the Navajo Dam, about 38 km west of the site, and two stations on and near the El Vado Dam, about 42 km east of the site. A preliminary reduction of the data shows that surface velocities recorded at the crests near the dam centers were about twice

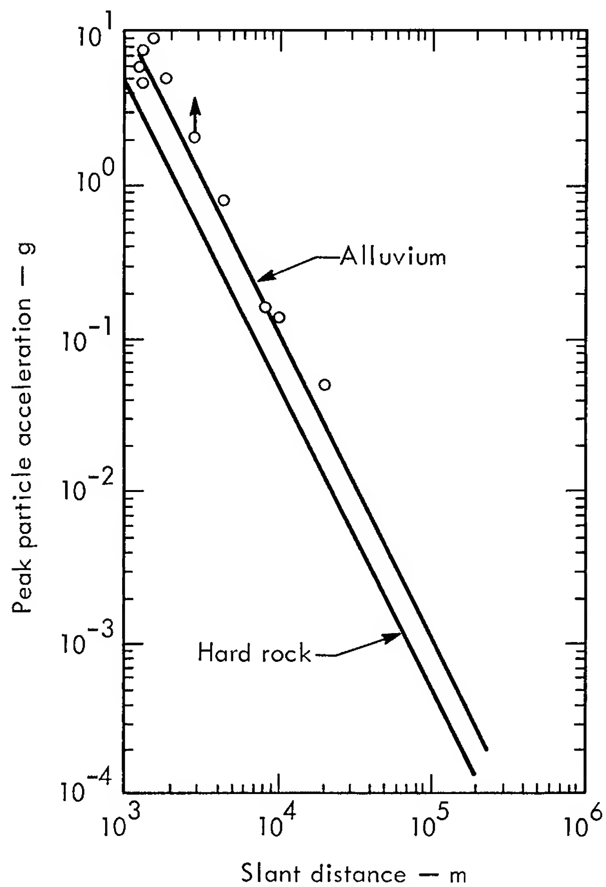

Fig. 5. Preliminary data, peak surface acceleration measurements. No attempt has been made on this figure or on Fig. 6 to separate the alluvium from the hard rock data while data are in this preliminary form.

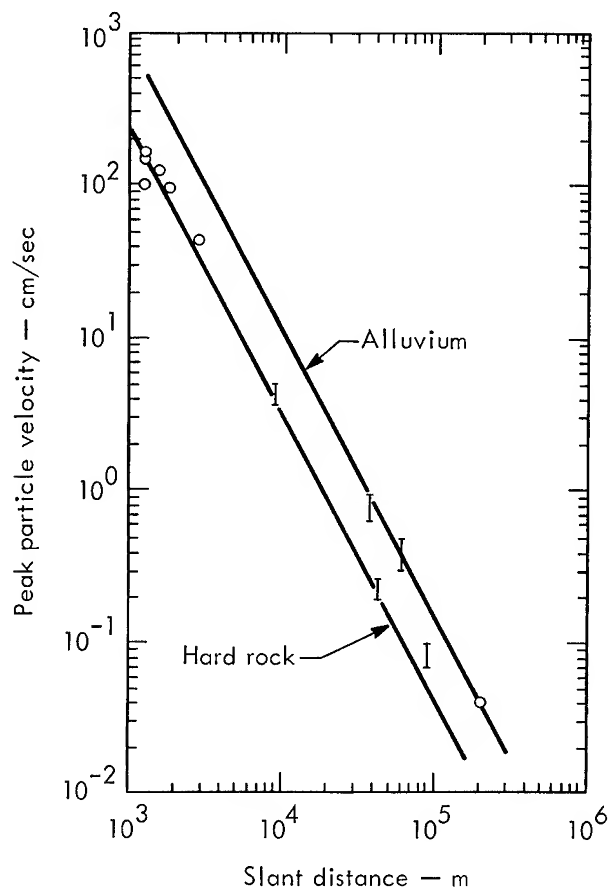

Fig. 6. Preliminary data, peak surface velocity measurements.

Table II. Close-in surface motion[a]

Location	Peak acceleration (g)			Peak velocity (cm/sec)		
	Vertical	Radial	Tangential	Vertical	Radial	Tangential
S-1	6.2[b]	0.5	—	159	6	—
100 ft from SGZ	16.0[c]	1.6	—	-168	-14	—
S-4						
400 ft from SGZ	8.0[b]	0.6	0.7	153	7	6
near well 10-36	20.0[c]	-2.3	-2.1	-153	12	6
S-15						
1500 ft from SGZ	4.4[b]	0.8	0.16	92	8	5
near GB-D	15.0[c]	1.6	2.4	-92	9	12
S-26						
2600 ft from SGZ	9.5[b]	1.0	0.9	113	40	17
near Trailer Park	30.0[c]	2.4	3.8	-116	27	6
S-42	5.0[b]	0.5	0.1	88	20	—
4200 ft from SGZ	11.6[c]	-4.0	-2.5	-113	-27	—
S-84	2.0 min[b,d]	0.6	0.1	40	11	24
8400 ft from SGZ	2.0 min[c,d]	-0.7	0.35	-40	9	—

[a]Data furnished by Sandia Laboratories.

[b]Values at peak of initial pulse.

[c]Values upon spall closure; for velocities, just before closure.

[d]Gage saturated at 2.0 g.

those measured at the base. No damage was observed at either dam. More extensive analysis is in progress.

STRUCTURAL RESPONSE

Thirty-one selected buildings were subjected to detailed preshot and postshot examinations. Sixteen of these were monitored during passage of the seismic wave. No new damage has been found in any of the examined structures, confirming the prediction of a low probability of damage. No damage was sustained by any of the underground tunnels in the area, and none has been reported from any of the mines.

POSTSHOT CHIMNEY INVESTIGATIONS

REENTRY DRILLING PROGRAM

Reentry drilling in hole GB-ER started on December 13, 1967. As planned, the drilling program consisted of removal of the sand and cement from the center of the 7-in. casing used to emplace the explosive (gas was used to remove the drilling chips). No deformed casing was encountered above 3800 ft, but the reentry operation was hampered by extremely cold weather and stuck drill pipe. Below a depth of 3300 ft the circulating fluid had to be changed to a lightweight drilling mud, since the cement was sufficiently moist to preclude further gas drilling. A differential temperature log established a water entry at a depth of 3553 ft through a cementing slot, with the water evidently coming through the open cement stage tool at 3548 ft. The rate of influx was about 2 cubic feet per hour. Chemical analysis of samples taken established the water to originate in the Ojo Alamo formation. Traces of radioactive xenon-133 were found in the water, as were barely detectable amounts of tritium.

At a depth of 3858 ft, a 6-ft void was encountered, and circulation was lost. No radioactivity was encountered, and a pressure of 48 psi was measured at the surface. Both the 7- and the 20-in. casing appear to have parted at this point.

A water level probe run into the hole at that time showed water standing at a level of about 1748 ft in the hole. Thirty barrels of water were then put into the hole, which should have raised the water level by some 800 feet. A re-run of the probe established the new water level at 1739 ft.

Drilling was then resumed (still through the 7-in. casing) with mud being injected at the rate of about one barrel per minute without circulation being established. On January 10, 1968, a 9-ft void was encountered at a depth of 3907 ft. At the bottom of this void the drill bit encountered steel, making further drilling impossible. About 20 min. later, radioactive xenon was detected at the surface. At that time it was concluded that connection with the chimney had been established. The distance of this point from the detonation center agrees well with the lower limit for a failure radius calculated preshot; the fracture data from GB-1 and from the geophysical logs in GB-ER indicate a fracture radius about 100 ft larger, or about 40 ft greater than the maximum fracture radius calculated preshot. These points should be cleared up by further postshot work being proposed.

GEOPHYSICAL LOGGING

A limited number of logs were run in the region below 3800 ft inside the 7-in. casing. These consisted of density, gamma-radiation, collar locator, and caliper. A borehole camera was also run in an attempt to examine the void between 3907 and 3916 ft. Only the gamma-radiation tool was able to reach a level of 3912 ft; its detector, located 6 ft above

the bottom of the tool, may not have been in the void at 3907 ft. By correlating these logs with each other, it can be concluded that a number of breaks or offsets have occurred in the casing, ranging from 3805 ft down to the void at 3907 ft. Comparing the location of these breaks with the preshot density logs in GB-1 suggests a direct relation between the breaks in the pipe and the major bedding planes of the rock.

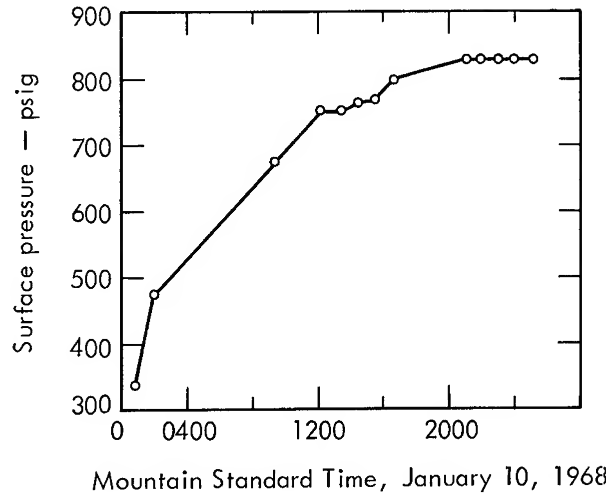

Fig. 7. Time history of surface pressure buildup, January 10, 1968.

STATIC GAS PRESSURE

The static gas pressure was read at the surface with a Heise pressure gage calibrated with a dead-weight gage and capable of a reading accuracy of better than 1/2 psi. The extremely cold weather and the presence of moisture made repeated heating of pipes necessary in order to keep gage lines open. This difficulty is probably responsible for some of the scatter in the pressure readings.

After the void at the depth of 3907 ft was penetrated, the pressure at the surface was monitored frequently. The time history of the buildup of this pressure is shown in Fig. 7. A maximum of 833 psig was read at the surface after about 20 hr. On January 23, 1968, a surface pressure of 840 psig was recorded.

Only fragmentary bottom-hole pressure measurements are available. On January 17, 1968, or one week after the initial encounter of pressure, a bottom-hole pressure gage measured a static pressure of 953 psig at the 3800-ft level while the surface pressure was 831 psig. A formation pressure of 1050 psi at the 4150-ft level was estimated preshot from the buildup curve of GB-1.

PRELIMINARY FLOW TESTS

About two days after penetration of the void at 3907 ft, a very limited number of low-volume flow tests were instituted. The purpose of these tests was to obtain a clearer idea of the concentration of radionuclides in the gas, and, if possible, of the nature of the connection with the chimney. In Flow Tests I and II, conducted on January 12, 1968 and January 12-13, 1968, respectively, gas was withdrawn from the 7-in. casing directly. Flow Test III, on January 17, 1968, took place after a production packer and 2-7/8-in. tubing had been set at 3797 ft. In all cases the gas was flared at the top of a 50-ft stack after passing through a bank of charcoal filters and a number of

liquid traps. A series of regulators between the well head and the filters kept the flow limited to the capacity of the filters and held the flow approximately constant. An orifice meter measured flow rates. The gas stream was continuously monitored at a number of places between the well head and the stack for the presence of radioactivities.

The decrease of the surface pressure as a function of time during Tests I and II is shown in Fig. 8; the start of Test II followed the start of Test I by 10 hr, 45 min. After Flow Test II, the pressure buildup was monitored, but icing of the gage resulted in erratic readings and the attempt was concluded after 1/2 hr.

After tubing was installed, Test III was carried out about 5-1/2 days after Test II. Flow rates during this test were about 1.5 M^2cfd, and a bottom-hole pressure gage and a thermometer were used. The pressure gage showed a decrease from 953 to 950 psig during the first 40 min of flow. A maximum temperature of 152°F was recorded during this run, which is about 25°F above the preshot ambient temperature. Figure 9 shows the pressure-time behavior of Test III.

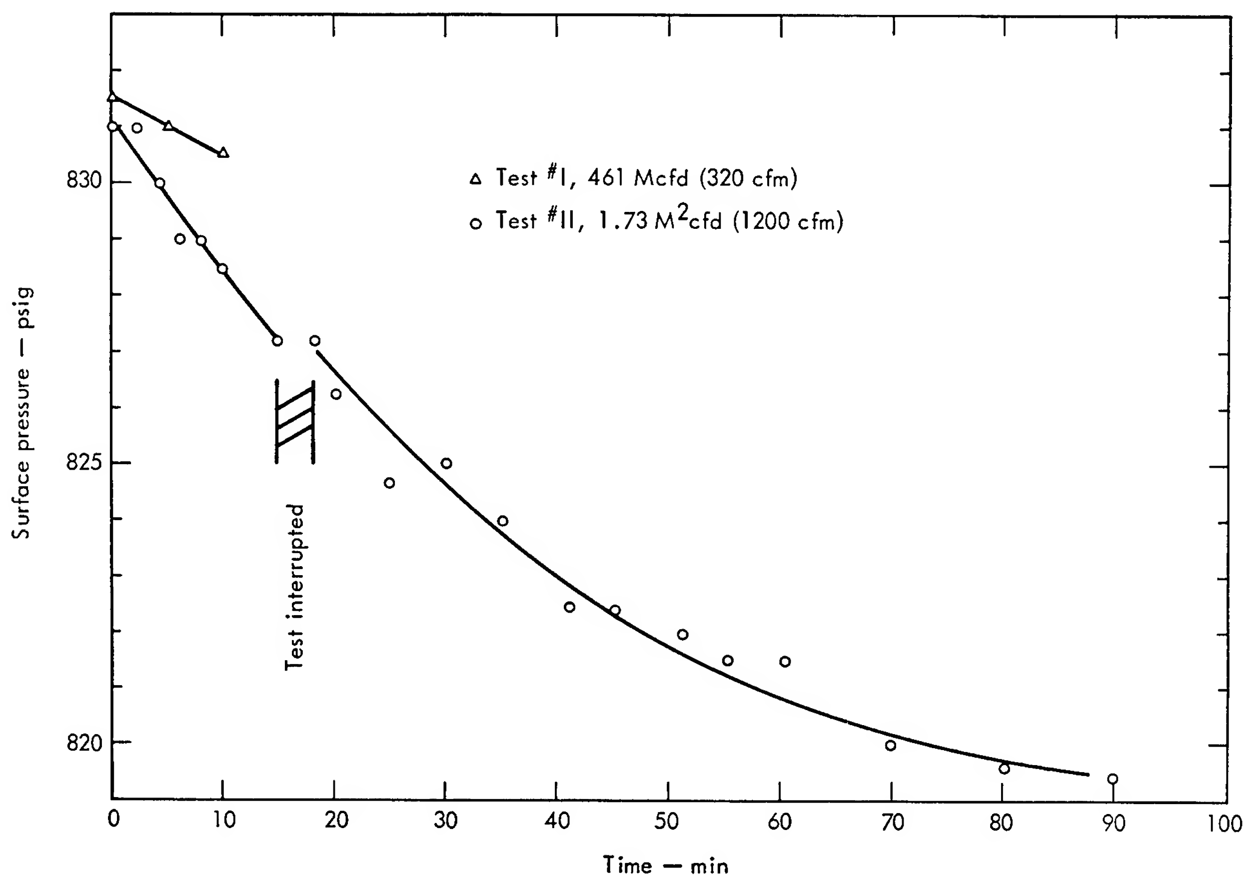

Fig. 8. Drawdown data, preliminary Flow Tests I and II.

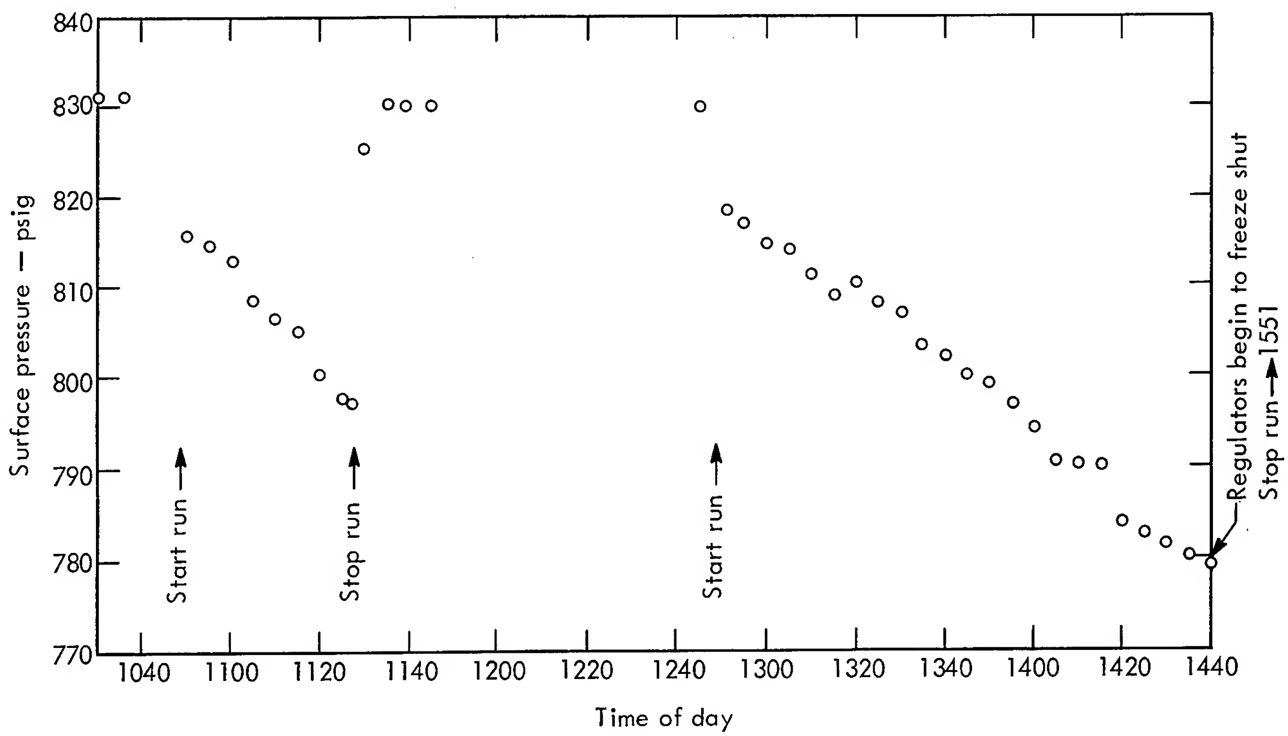

Fig. 9. Drawdown data, preliminary Flow Test III.

CONCENTRATIONS OF RADIONUCLIDES

Periodic gas samples were taken and analyzed at the site during and after the flow tests to establish concentrations and to document the total release. In addition, surface and bottom hole gas samples were collected in evacuated bottles for a more thorough analysis at LRL.

The only radioactive constituent detected in the gas at the site during the flow tests was xenon-133, which emits gamma rays of 80-kV energy with a half life of 5.3 days. Its concentration measured at the flaring stack during Flow Test I was 4.5×10^{-2} μCi/cm^3, and during Flow Test III, 1.1×10^{-2} μCi/cm^3.

No iodine was detected in the samples analyzed at the site or on the charcoal filters in the gas stream, even though the detection efficiency for iodine is about 10^5 greater than that for xenon.

As previously mentioned, some tritium was detected in water samples taken while investigating the water influx into the 7-in. casing at the 3550-ft depth. The levels were very low—approximately three times the natural background. No tritium was detected in any of the samples taken during and after the flow tests and analyzed at the site.

Laboratory analysis of the gas samples is currently in progress, but no results are available at this time.

DISCUSSION

Results available from the GB-ER reentry and exploration are not very extensive at this time; more will accumulate as data are analyzed and evaluated. The fact that connection with the chimney was established is clear from the pressure and radioactivity encountered. The dynamic fracture data and the results of the geophysical exploration indicate that the extent of rock failure was about as expected. The flow data obtained cannot be considered significant relative to either reservoir evaluation or chimney volume determination, nor were they meant to be so. Their main purpose was to explore the general nature of the connection of GB-ER with the chimney region. It is this author's opinion that the results available at this point in time from the total postshot program are not consistent with a picture that depicts GB-ER communicating cleanly with a region of high permeability. This opinion is not shared by the EPNG participants in the technical program who contend that the data are too limited and sufficiently confusing to preclude any conclusions at this time. Whatever the resolution of this question may be, it is clear that more work is needed before a conclusion can be reached with respect to the gas stimulation objective.

ACKNOWLEDGMENTS

This report could not have been written without the cooperation of many individuals and organizations in making early results available to the author. In particular I wish to thank W. Perret and B. Murphey of the Sandia Laboratories for much of the close-in surface and subsurface data, D. Edwards and R. Kinnaman of the Atomic Energy Commission and K. King of the U. S. Coast and Geodetic Survey for the more distant ground motion and structure response information, and H. Kendrick of El Paso Natural Gas Company for information on bottom-hole pressures, temperatures, and data on the surrounding wells. Throughout the chimney investigation and particularly with respect to the flow tests, the help and advice of C. Atkinson of the U. S. Bureau of Mines was welcome and valuable, as were the many conversations with L. Truby, W. Cutler, and W. Martin of EPNG. Lastly, I wish to express my appreciation to my colleagues at the Lawrence Radiation Laboratory for their unstinting cooperation.

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Technical and Safety Program Reports Expected from Participants in Project Gasbuggy

TECHNICAL REPORTS—(already issued)

Authoring Organization	Report No.	Report Title
EPNG/AEC/USBM/LRL	PNE-1000	Project Gasbuggy (Feas. Study Rpt.)
LRL	PNE-1001	Pre-Shot Summary
LRL	PNE-1003	Preliminary Post-Shot Summary

TECHNICAL REPORTS—(to be prepared)

Authoring Organization	Subject
SL	Free-Field and Surface Ground Motions (PNE-1002)
LRL	Prediction and Results of Dynamic Effects
LRL	Analysis and Interpretation of Gaseous Radioactivities
LRL	The Gasbuggy Seismic Source
LRL	Response of the Navajo and El Vado Dams
EPNG-USBM-LRL	Reservoir Geology
EPNG-USBM	Post-Shot Flow Tests
EPNG-USBM	Reservoir Analysis

SAFETY REPORTS—(to be prepared)

Authoring Organization	Subject
EIC	On-Site Radiological Safety
USPHS	Off-Site Radiological Surveillance
ESSA/ARFRO	Weather and Radiation Predictions
II	Ground Water Safety Evaluation
ERC	Analysis of Ground Motion and Containment
USBM (BuMines)	Mine and Well Safety
JAB	Structural Response
USGS	Geology and Hydrology
USC&GS	Seismic Measurements

ABBREVIATIONS FOR ORGANIZATIONS

USAEC	U. S. Atomic Energy Commission
EIC	Eberline Instruments Corp., Santa Fe, N. M.
EPNG	El Paso Natural Gas Co., El Paso, Texas
ERC	Environmental Research Corp., Alexandria, Va.
ESSA/ARFRO	Environmental Science Services Administration/Air Resources Field Research Office, Las Vegas, Nev.
II	Isotopes, Inc.
JAB	John A. Blume & Associates, San Francisco, Calif.
LRL	Lawrence Radiation Laboratory, Livermore, Calif.
SL	Sandia Laboratory, Albuquerque, N. M.
USBM	Bureau of Mines, U. S. Department of the Interior
USC&GS	U. S. Coast & Geodedic Survey, Las Vegas, Nev.
USGS	U. S. Geological Survey, Denver, Colo.
USPHS	U. S. Public Health Service, Las Vegas, Nev.